EVOLUTION OF A SWISS ALPINE FLOODPLAIN OVER THE LAST 150 YEARS: HYDROLOGICAL AND PEDOLOGICAL CONSIDERATIONS

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Abstract: Two main types of landscape characterize the floodplains of the alpine arc: areas where the river runs free, and others where the river is embanked. Both the natural alluvial activity (sedimentation, erosion) and the anthropic planning (embankment, drainage) are involved in this landscape diversity. In addition, two general principles influence the human interventions: security (hydraulic, alimentary, energetic…) and conservation of biodiversity (natural floodplains). Between 1850 and about 1970 emphasis was almost exclusively made on security, but now, this unilateral concept is questioned. So, both security and nature conservation (biodiversity) will be positively complementary in the future. To illustrate this general change, a Swiss alpine floodplain is studied in details. The area of study is situated in the north of the Swiss Alps along a 12-km section of the Sarine River, which flows into the Aare River (a tributary of the Rhine River). Two research fields are investigated in this study: fluvial geomorphology (the exceptional floods, the river morphology and dynamic) and ecology (the relationships between vegetation and soil). The aim of this research is to understand the evolution of the relationships between the two general principles, mentioned above, between 1850 and 2000, in the Swiss Alps. Through an analysis of the exceptional hydrological events, the impacts of human structures on the landscape and the river morphology are evaluated to establish tools for a new floodplains management. This paper presents the first results of an interdisciplinary study of a floodplain landscape evolution combining here geomorphological and soil science approaches. Socio-economic issues related to floodplain transformations are currently addressed in a parallel study, which analyses legal aspects of the environment and the exploitation of resources over the last 150 years, as well as the representation of the landscape and risk are examined.

INTRODUCTION

An alpine or pre-alpine dynamic floodplain is conditioned by two main variables, the water discharge and the matter fluxes, which consist in a large amount of sediments transfered from the upper catchments to the valleys. Both contribute to the geomorphological diversity of the floodplain like other variables such as the valley global slope and the sedimentary characteristics of the riverbed and riverbanks. Erosion, transport and deposition in this active zone create also an important ecological diversity through a permanent drop in age of the fluvial forms and the vegetal successions.

Braided rivers were in the past one of the most typical landscape of Swiss alpine and pre-alpine valleys as it was the case in the French Alps for example (Bravard, 1989; Bravard & Peiry, 1993). Since the middle of the 19th century, this landscape has progressively disappeared largely due to the development of flood protection structures and the water exploitation for energetic and food security reasons. Historically, the first modifications to the river systems have been flood protection measures (Vischer, 1989), which occurred during the nineteenth century in the Swiss Alps. The 1834 flood caused serious damages and showed the necessity to give up the local and community flood protection systems and to think protection against floods in a more systematic way (Nienhaus, 2002).

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But it's only after the creation of the Federal State and the catastrophic flood of 1868 (Schmid, 2002), that the Water Policy Act of 22 June 1877 was enforced, allowing the systematic regulation of most of the alpine river flows through federal grants. As water and matter fluxes had to be contained and regulated, the first works were made in the high alpine torrents and their catchments and consisted largely of slope reforestation and "torrent extinguishing". These regulations caused streambed incision processes and a progressive landscape evolution as well as a biodiversity loss. These modifications are well documented in the French Alps context (Blanc et al., 1989; Bravard, 1997; Bravard et al., 1997; Pautou et al., 1997; Piégay & Peiry, 1997), but few studies were made in the Swiss Alps.

Because of this high degree of man induced alteration during the end of the nineteenth and the first part of the twentieth century and to ensure the safeguard of these particular ecosystems, the European Council (Conseil de l'Europe, 1982) asked its member states to make an inventory of their alluvial zones with the aim of conservation, protection and restoration. Many studies of the dynamic of the alluvial vegetation were produced at the European level, particularly in France (Bravard et al., 1986; Pautou et al., 1997), and at the Swiss level (Gallandat et al., 1993; Roulier, 1997). On the other hand, only few studies were focused on alluvial soils. In a Swiss context, researches exist concerning the formation and evolution of young soils (Bureau, 1995; Bureau et al., 1995; Mendonça Santos et al., 1997; Mendonça Santos, 1999). A better knowledge of short–term evolution processes, through a study of the sedimentation (ancient soil layers) and erosion dynamics, is nevertheless useful to provide a dynamic image of the alluvial landscape over the last two centuries.

The interdisciplinary study related to this paper is one of the rare attempts to analyse the Swiss floodplain modifications since the middle of the nineteenth century. Precise information of the landscape dynamics is necessary to define future actions allowing the preservation of the alluvial ecosystem (Girel et al., 1997). So, the general aim of the study is to bring to light, through an analysis of the exceptional events, the evolution of the relationships between two general principles that are security and conservation of biodiversity during the last 150 years. This present paper presents the first results of a floodplain landscape evolution, combining here geomorphological and soil science approaches, which provide a detailed history of the valley helping us, with the sociological results, to establish tools to help decision making for floodplains management.

AREA STUDIED AND METHODS

The Sarine River is situated in the northwest of the Swiss Alps and is the tributary of the Aare River, which flows then in the Rhine River (Fig. 1.). The study section length is 12 km between Neirivue (745 m) and the Gruyère Lake near Broc (670 m) with an average slope of 0.6‰. The geomorphology of the section is characterized by a succession of alluvial basins separated by rocky constrictions (Fig. 2.). The catchments area is 639 km2 with an average altitude of 1520 m. From 1972 to 2001, the maximum annual peak discharge was 400 m^3/s in 1974 and the mean annual discharge is 217 m^3/s.

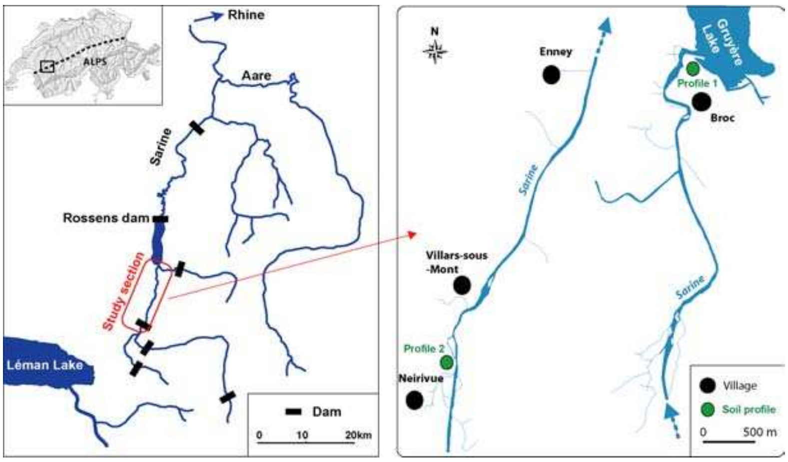

Figure 1. Geographical location of the study section on the Sarine River.

The area is of interest because it has been well documented over the years, thus allowing researches to evaluate the transformation of this floodplain. Two main methods were used to reconstruct the functioning of the system before and during the period of human impact. First an historical approach using old maps (scale 1:25'000) and embankment plans (scale 1:2'000) and information about human activities was chosen to provide the geomorphological context of the valley. A series of maps between 1888 and 1980 and different plans were used in order to illustrate changes in the fluvial pattern and then the causes of these modifications were explained through historical archives. Secondly, the nature of the soil deposits were surveyed by describing in details the morphology of two different soil profiles. At the point of this research, the approach is only descriptive.

The first profile (Profile 1, Fig. 1.) is situated in an active zone (willow wood with *Salix alba*) near Broc on the South shores of the Gruyère Lake. This site is annually slightly inundated because of the regulation of the Gruyère Lake level through Rossens dam. The other site (Profile 2, Fig. 1.) is located near Neirivue in an embanked zone (cultivated grassland) where no flood has been observed since the embankment constructions (between 1920 and 1930). The main factors for the description are the textural properties and the thickness of the different horizons, the presence of organic matter and oxidation-reduction marks in the profile. These two profiles are in two different locations, but they are both submitted to alluvial processes. The FAO and the ISSS Working Group RB references (FAO, 1988; ISSS Working Group RB, 1998) were used to describe the horizons and the soil profiles.

RESULTS AND DISCUSSION

Fluvial corridor modifications of the Sarine River and the causes of change

Even if general embankment plans existed at the end of the nineteenth century, authorities adopted in 1916 the first systematic general plan for the Sarine River with the aim of preserving the riverside fields against floods and bank erosion. This decision was the consequence of the catastrophic flood of 1913, which necessitated immediately huge works to strengthen the Sarine riverbanks. These first embankments began during the First World War and were conducting up to 1938. A general diking and canalization with one pair of continuous and unsinkable dikes were made to collect the flows in a single uniform channel. The consequences were the narrowing of the potential river divagation and the riverbed incision.

The modifications of these first embankments are shown on the Fig. 2. In the alluvial basin upstream (1), the main impact of flood protection structures is the disappearance of multiple channels replaced by one single channel and the progressive colonization of gravel surfaces by vegetation. The next alluvial basin (2) shows the same features with the drastic change of the braided river in 1890 to the straightened section in 1933 near the village of Enney. The modifications are however less pronounced in the third alluvial basin (3) and the flat floodplain downstream near Broc (4), where a loss of vegetation is noticed due to the development of agriculture. After the 1944 flood, a further embankment project was led to reconstruct the damaged structures and to build new ones. These works were made between 1944 and 1954. So during almost 40 years, the Sarine was progressively straightened and disconnecting from their floodplain. The creation of the Gruyère retention lake in 1946 (4) caused the total disappearance of a very dynamic floodplain. From a typical floodplain landscape with numerous channels, gravel bars and alluvial vegetation, the Sarine corridor has progressively evolved to a landscape characterized by a straight channel with few gravel bars and riverbanks, where the typical alluvial vegetation is replaced by new plant successions.

After 1960, two main human activities had contributed to increase the bed incision and the disconnection of the river with its floodplain: the gravel mining and the water retention by dams in the upper catchments. Between 1960 and 1976, gravel was removed directly from the river bed and the combination of this activity with the sediment retention upstream contributed to accelerate the river bed incision process already initiated with the systematic river embanking Thus, erosion was favored in comparison to sedimentation. The analysis of cross sections has shown an average incision of about 2 meters with a maximal incision near Enney of 5.3 meters since 1916! So our study reach presents in the 1980 years a single straightened channel with few alluvial vegetation covers and a riverbed well incised which indicates that geomorphological and ecological diversities are now low.

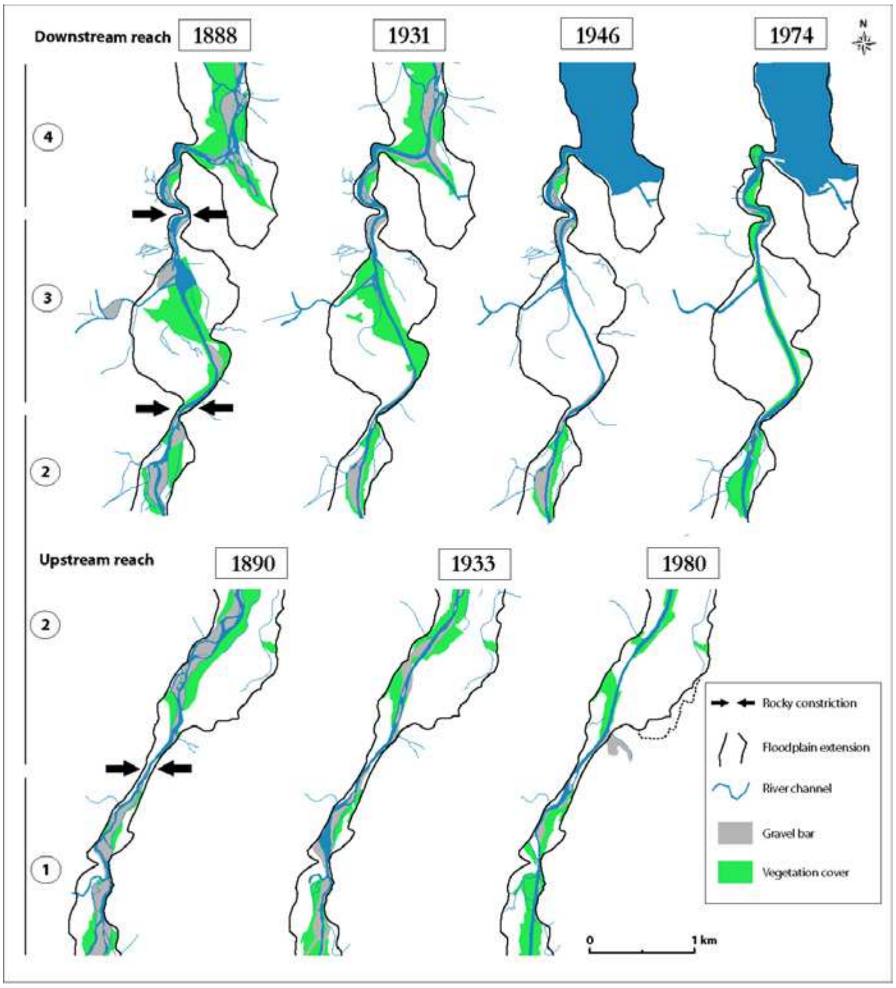

Figure 2. Changes in the channel pattern between 1888 and 1980 using ancient maps.

Soil descriptions and interpretation

The profile 1 has been classified as a calcareous fluvic polygenetic GLEYSOL with oximorphic properties (Tab. 1.). It presents a deep water table, which rises seasonally to saturate the whole solum. The distinctive features of this profile are the alternation of fine- and coarse-textured horizons in the entire profile and the presence of a deep organic layer (XAbg).

Table 1: Morphological properties and description of the profile 1. Texture: 1 = sand, 2 = loamy sand, 3 = loam, 4 = clay loam, 5 = clay, 6 = gravels and 7 = rocks. Oxidation/reduction marks: 0 = none, 1 = oxidation marks prevailing, 2 = oxidation and reduction marks, 3 = reduction marks prevailing. Organic matter: 0 = absence and 1 = presence. Roots: 0 = absence, 1 = few, 2 = common, 3 = many, l = large, m = medium, f = fine and vf = very fine. Boundary: A = abrupt, G = gradual, I = irregular, S = smooth and W = wavy.

Horizon	Depth (cm)	Color	Texture	Oxidation/reduction marks	Organic matter	Roots	Boundary
A	0-8	brown	3	0	1	2m	AS
Bg	8-14	brownish grey	4	1	1	1f	GW
IIBg	14-19	brownish grey	2	1	1	1vf	GW
IIICg	19-28	grey	4	2	0	1vf	AS
IVCg	28-31	light brown and orange mottles	4	1	0	1f	AS
VCg	31-36	grey	4	3	0	1m	AS
VICg	36-43	brown and orange mottles	4	2	0	1vf	AS
VIICg	43-46	grey	3	2	0	1f	AS

VIIICg	46-50	grey and orange mottles	2	2	0	1vf	AS
IXCg	50-52	grey	4	3	0	1vf	AS
XAbg	52-75	dark brown	2	1	1	1f	AW
XICg	75-81	grey	1	1	0	0	AW
XIICg	81-94	brownish grey	1	2	0	0	AS
XIIICg	94-102	grey	6	2	0	0	AS
XIVR	102+	grey	7	2	0	0	--

The vertical heterogeneity with relative abrupt boundaries means that the soil is continually constrained by the process of deposition, however the nature of the sediments, more fine-textured within 50 cm of the surface, indicates a slow flow and a smooth sedimentation. The buried organic layer indicates that the top of the profile was at this level for a while, probably before the formation of the Gruyère Lake. The bottom of the profile with coarse-textured sediments (gravels, rocks) suggests a sedimentation process with a rapid flow velocity.

Another characteristic of this profile is the presence of distinctive gley horizons (orange and grey mottles) that result from the oxidation-reduction process in almost the entire profile. Due to the regulation of the Gruyère Lake, this soil is regularly saturated with water and the sedimentation and current speed are very slow. This is reflected also by the nearly horizontal boundaries.

The profile 2 has been classified as a calcareous polygenetic FLUVISOL. The topsoil horizons are very homogenous and not really different as far as mineralogy is concerned (Tab. 2.). The profile is influenced by water within the profile (oxidation and reduction marks) but no more by sedimentation. This is a typical agricultural soil where the human influence is restricted to the surface horizons and an intact buried alluvial soil is found in depth.

Table 2: Morphological properties and description of the profile 2 (see Tab. 1. for the caption).

Horizon	Depth	Color	Texture	Oxidation-reduction marks	Organic matter	Roots	Boundary
A	0-8	brown	3	0	1	2m	GW
Bg	8-40	light brown	4	0	1	1f	GW
IICg	40-60	light brown	3	1	0	0	AW
IIICg	60-73	greyish brown	2	2	0	0	GW
IVCg	73-76	greyish brown	2	2	1	0	IW
VCg	76-86	grey and orange mottles	2	1	1	0	IW
VICg	86-95	grey	1	3	0	0	IW
VIICg	95-100	grey	2	1	0	0	AS
VIIICg	100-103	grey and orange mottles	1	1	0	0	AW
IXR	103+	grey	7	3	1	0	--

These first considerations confirm that alluvial soils are very heterogeneous and linked by the processes of sedimentation and the landforms that are created (Gerrard, 1987). Even if the studied points are located at two different places, the soils are under the influence of the river processes and show a common nature, as at the bottom of the two profiles. But when human impacts modify the nature of the river, the soil reflects these changes.

CONCLUSION

These first results show the geomorphological evolution of the Sarine river valley due to the human impact. The embankments had greatly modified the landscape of the Sarine valley during the last 150 years with an incision of the bed river and a decrease of the plant successional stages typical of floodplain. The study of two different profiles of soil also demonstrates a change in the soil formation and evolution. The alternation of layers, particularly within the 50 cm of the surface is more striking in the active area than in the embanked zone. More studies related to the landscape change will be done using aerial photographs from 1930 and now. These further results, combining with the sociological study, will be necessary to understand the evolution of the representation of floodplains by different actors and through time.

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